

Synthesis and Review of Environmental Conditions in Gloucester Harbor

Anthony R. Wilbur

Massachusetts Office of Coastal Zone Management

Fara Courtney

Good Harbor Consulting, Gloucester, MA

ABSTRACT

The environmental quality of Gloucester Harbor is typical of an urban port, characterized by areas of degradation and areas of limited human perturbation. Recent studies and monitoring of Gloucester Harbor provide the foundation to evaluate current environmental quality, pollution sources, and contaminant threats. The current status of Gloucester's marine environment is the product of nearly 400 years of anthropogenic stress from point (wastewater discharge) and non-point (urban runoff) sources of pollutants, coastal development, and hydrologic modification. The inner harbor shows substantial human-induced degradation, indicated by prevalent sediment contamination and episodic low dissolved oxygen levels. The outer harbor exhibits human influences, but to a lesser degree than the inner harbor. Environmental quality has improved to current conditions from a severely degraded period of unregulated discharge and harbor use, but Gloucester Harbor still bears evidence of its industrial history.

EFFECTS OF DEVELOPMENT AND INDUSTRIALIZATION

The combination of historic and recent human activities contributes to the environmental integrity of Gloucester Harbor. Environmental resources were altered and are threatened by direct (e.g., hydrologic modification), indirect (e.g., loss of prey or degradation of habitat condition), harbor-specific (e.g., contaminated sediments), and regional (e.g., sea level rise) impacts. These anthropogenic and natural threats vary through time and space. The individual, cumulative, and/or synergistic nature of threats affect biotic and abiotic properties of Gloucester Harbor waters.

The marine environment of Gloucester is influenced by point discharges (e.g., wastewater outfall and combined sewer overflows) and non-point sources, such as urban and residential runoff, groundwater inputs, and vessel-related discharges. The foundation and development of Gloucester, unregulated and regu-

lated effluent, and coastal alteration during the past four centuries modified the natural landscape and environmental conditions. Seafloor sediments, in particular, provide evidence of historic pollutant loadings to Gloucester Harbor (Maguire 1997; Valente et al. 1999; MCZM 2000). Contaminants found in seafloor sediments and the water column introduce acute and/or chronic effects on marine life and pose potential risk to human health.

The Gloucester waterfront supports a productive maritime industry and a concentrated human population. The Clean Water Act (1972) initiated environmental awareness and regulation, and environmental quality improved to current conditions from a period of unregulated harbor use. Contemporary resource management attempts to balance the protection of natural resources and promotion of sustainable use. Despite dramatic improvements in environmental conditions since the 1970s, Gloucester Harbor still bears evidence of its industrial history. Environmental implications of creating a working waterfront were

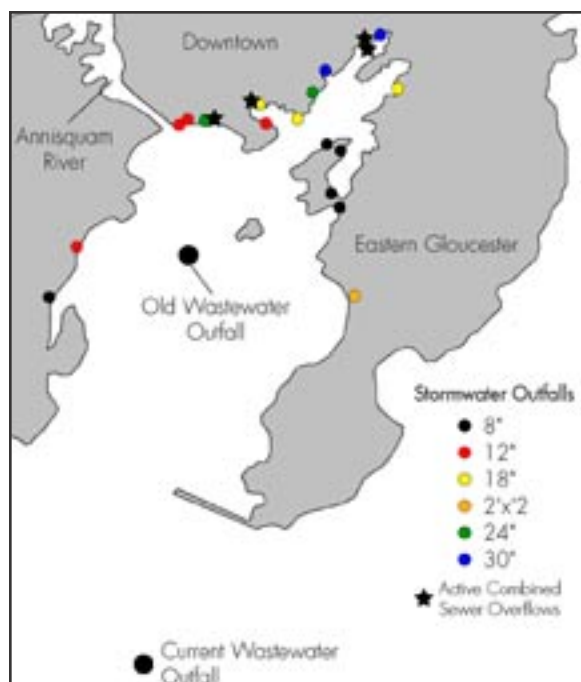


FIGURE 2.1 Pollution sources, previous and existing wastewater outfall, combined sewer overflows (CSOs), and stormwater drains (Metcalf and Eddy 1992).

not thoroughly evaluated through time, but human population growth, incremental filling of tidelands, construction and alteration of the harbor shoreline and seafloor, and development of the harbor watershed affected harbor environmental quality.

Environmental resources are sporadically evaluated, through time and area, for Gloucester Harbor. The patchy network of studies and assessments are not summarized to describe the current status of resources and environmental quality. The objective of this report is to identify sources pollution and physical disturbance, describe impacts and threats from human perturbation, and evaluate the current environmental quality of Gloucester Harbor. The report also discusses cumulative impacts and environmental attributes that require further evaluation to determine status and trends.

POLLUTION SOURCES AND THREATS

Forty-one discharges are located within Gloucester Harbor that require a National Pollutant Discharge Elimination System (NPDES) permit. Forty of the

permits are classified as minor discharge facilities (i.e., discharge less than 1 million gallons per day) and are predominately found in the inner harbor. The only major facility is the Water Pollution Control Facility (WPCF) on the Annisquam River with the outfall located south of Dog Bar Breakwater (Figure 2.1).

Regulated point discharges include the wastewater treatment facility and four active combined sewer overflows (CSOs) (Figure 2.1). CSOs are located in the North Channel (2), Harbor Cove, and Pavilion Beach. The four active CSOs discharge urban and residential runoff during wet weather.

Seventeen storm drains are located around the harbor and annually discharge an estimated 575 million gallons of stormwater (Figure 2.1; Metcalf and Eddy 1992). Stormwater influences environmental conditions by discharging untreated sewage and urban and residential runoff into Gloucester waters. Runoff and stormwater contain a number of pollutants, including heavy metals, organic compounds, and hydrocarbons.

Spills, landfills, and historic waste disposal activities were investigated to determine pollution sources to Gloucester Harbor (Figure 2.2; Maguire 1997). Three substantial aquatic spills (accidental discharge of contaminant directly to water) occurred since 1990, including petroleum and diesel fuel. Hundreds of spills on land occurred in Gloucester during the past 10 years. Spills (on land) and Emergency Response Notification System (ERNS, Environmental Protection Agencies response database) reports included petroleum products (e.g., diesel fuel) and contaminants, including benzene, ammonia, and lead.

Approximately 20 Comprehensive Environmental Response Compensation and Liability Information System (CERCLIS) sites are located on and near the shoreline of the Gloucester (three mapped). The CERCLIS sites are classified as NFRA (no further remedial action); however, sites may contain a measure of contamination. Fifty state hazardous waste sites are found throughout Gloucester, predominately characterized as areas contaminated by petroleum and associated products, and may release polychlorinated biphenyls (PCBs), petroleum hydrocarbons,

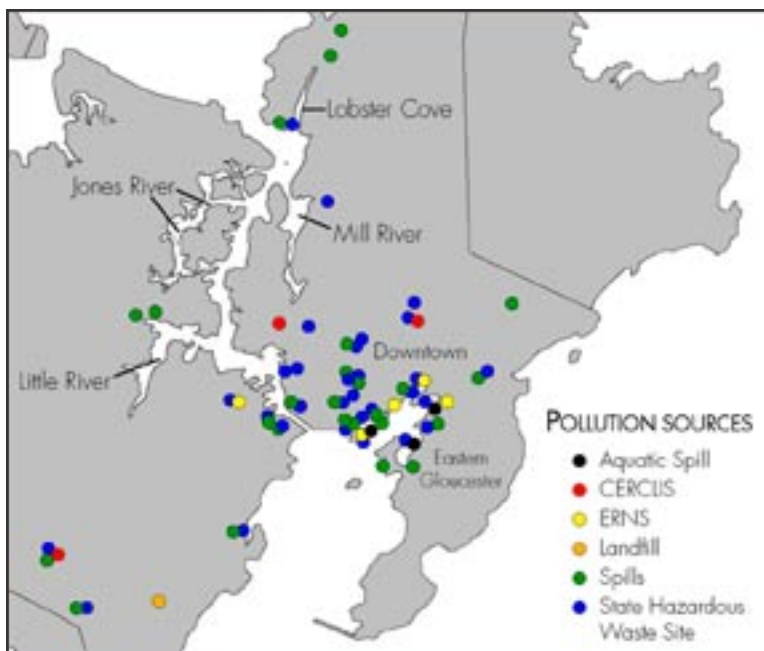


FIGURE 2.2 Pollution sources in Gloucester (Maguire 1997). CERCLIS (Comprehensive Environment Response Compensation and Liability Information System); ERNS (Emergency Response Notification System).

volatile organic compounds, and heavy metals to the soil, surface water and groundwater (DeCasare et al. 2000). These pollutants potentially settle to the seafloor and bind to sediments.

Coastal development and changes to the harbor environment dramatically altered Gloucester Harbor's landscape and marine resources. Vegetation was cleared, coastal and intertidal habitats were filled, and land was developed around the naturally deep harbor to create a working waterfront. The harbor attracted a concentrated population and industrial development. Non-point source pollutants are associated with industrial, commercial, and residential land use, intense waterfront development, and waterside use by recreational and commercial vessels.

Organic waste, hydrocarbons, heavy metals (e.g., tin- and copper-based paints), fertilizers and pesticides, pathogens, and suspended solids threaten environmental conditions in Gloucester Harbor. In addition to identified sources, fish processing, land-based and water-side transportation, vessel servicing activities, landscaping and lawn care, marine head discharges, urban and residential runoff, and atmospheric deposition potentially contribute to environmental stress (Maguire 1997). Contaminated seafloor sediments

are a reservoir of pollutants that can be disturbed and resuspended, presenting an additional threat. Centuries of development created impervious surfaces (e.g., roads, parking lots, roofs, cultivated fields) that exacerbate the runoff and associated pollutants entering Gloucester Harbor. Areas within the Gloucester watershed are unsewered, and septic systems present a source of contamination. Historic, unregulated industrial and sewage effluent contributes to current environmental conditions, and threats continue to be conveyed by point and non-point sources.

HYDROLOGIC MODIFICATION

Coastal, intertidal, and subtidal habitats were filled and dredged, and portions of the coast were armored to create the modern shoreline of Gloucester Harbor (ICON 1999). It is estimated that over 80 acres of intertidal and submerged habitat was filled to create the present-day harbor (ICON 1999). The change from natural conditions is dramatic, particularly the elimination of Vincent's Cove and Fivepound Island. Filling intertidal and subtidal habitats resulted in permanent loss of natural resources and potentially caused substantial changes to hydrologic properties (e.g., removal of coastal vegetation eliminated the function of vegetation to uptake pollutants). There is no quantitative assessment through time of specific wetlands or coastal habitat loss or other potential impacts from dredging, filling, or construction in Gloucester Harbor.

Fill and construction throughout the inner harbor, particularly the development of the State Fish Pier, is assumed to have affected circulation. Low elevation lands, possibly wetlands, were armored and filled between Rocky Neck and East Gloucester. The Blynman Canal created a permanent connection between Gloucester Harbor and the Annisquam River, expanding the harbor watershed to include an estimated 4.61 km² drainage area (i.e., Little River subwatershed) (Kookan et al. 2000). Hydrologic

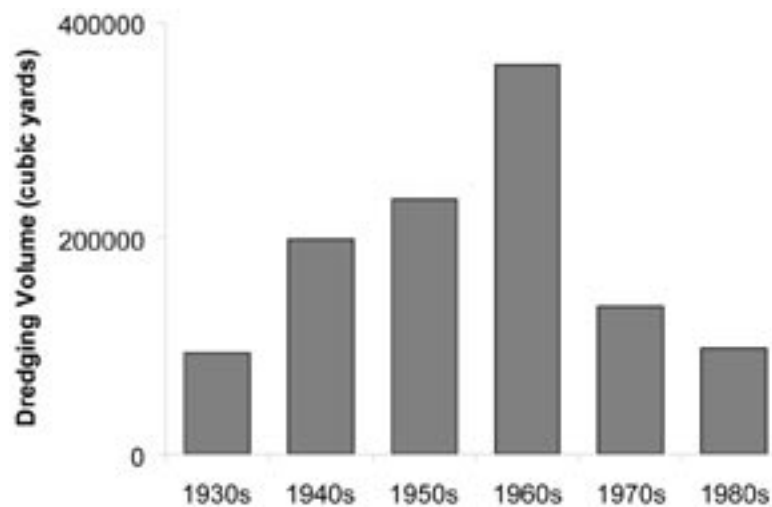


FIGURE 2.3 Dredging volume from Gloucester Harbor and Annisquam River from 1930-1990. Dredging volume is based on permitted operations (USACE 1996).

analysis does not exist to illustrate the extent of Annisquam River flow to Gloucester Harbor, but river drainage to the harbor contributes a volume of water that influences circulation, tidal patterns, and overall water quality. Dog Bar Breakwater also altered water circulation in the outer harbor.

Channels and anchorage areas were created to improve and maintain navigation. Larger vessels harboring in Gloucester necessitated substantial dredging by the late 1800s. Navigation channels were constructed and deepened by the U.S. Army Corps of Engineers. The creation of navigation channels inherently impacted seafloor conditions and water movement. Channel dredging is a periodic maintenance activity associated with port and harbor development (see Barr 1987 for review), and navigation channel maintenance, city dredging of smaller parcels, and private dredging (e.g., marinas) routinely occurred during the development of Gloucester Harbor. A total of 1,178,370 cubic yards were dredged since 1932 in Gloucester Harbor and Annisquam River (Figure 2.3; USACE 1996). This figure does not incorporate dredging that occurred prior to 1932, which included a substantial volume of dredged material.

Dredging, including maintenance and improvement projects, resuspends sediments and associated contaminants, alters seafloor structure (i.e., sediment

type and topography), and removes surficial flora and fauna (Messieh et al. 1991). Short-term impacts may be substantial to local biota and habitat conditions. Dredging and port development results in the congregation of marine industries and aggregates contaminants derived from maritime industry. Harbor development also congregates coastal development that can concentrate pollutants entering harbor waters. The identifiable pollutant sources found on working waterfronts can contribute to seafloor sediment contamination.

Mooring fields are found throughout Gloucester Harbor and Annisquam

River. Smith Cove is covered by moorings, and Ten-pound Island, Niles Beach, Dog Bar Breakwater, and Freshwater Cove provide moorings for recreational boaters. The Annisquam River, including areas adjacent to the navigation channel, Lobster Cove, and Little River, are crowded with moorings. Mooring chains scour seafloor habitats, including eelgrass, potentially altering and impairing benthic resources.

WATER QUALITY

Water quality is influenced by historic and existing harbor industries and watershed land use characteristics. Fish processing plants and domestic sewage currently present problems, and sediment contamination influences water quality (Kookken et al. 2000). The earliest evaluation of Gloucester water quality occurred during a period of severe degradation (Whitman and Howard 1958), when untreated wastes were directly discharged to the harbor. The original wastewater system centralized the downtown effluent, and 4 million gallons of wastewater (sanitary sewage and industrial waste) were released to the middle of the outer harbor per day (Whitman and Howard 1958; Kookken et al. 2000). The majority of industrial waste was generated by fish processing plants, containing fish waste, oils, and grease by-products. There were also a number of private and combined sewers in the downtown area directly discharging waste to the harbor (Whitman and Howard 1958).

The 1958 report included a visual survey and described the area near Pavillion Beach and the Harbor Cove shoreline as clearly polluted with water discolored by industrial waste and floating solids. Banks of sludge (i.e., mix of organic matter and fine-grained sediments) formed along the shoreline and produced gas bubbles, indicating active decomposition of organic material. Boats maneuvering in Harbor Cove stirred up fish scales. The study noted that residential areas on the east side of the harbor, including Rocky Neck, were directly discharging sanitary sewage to harbor waters (Whitman and Howard 1958).

Water quality during that period may be a snapshot of the poorest environmental quality in Gloucester Harbor's environmental history. The "Swim for a Clean Harbor" started in 1979 to raise public awareness of the harbor's poor water quality, and during the first few years participants described swimming through oil, raw sewage, and gasoline (Flemming 1982). The situation improved through time with the implementation of environmental regulations to protect resources. Water quality assessments are currently focused on the WPCF, CSOs, and bacterial contamination (e.g., fecal coliform) of shellfish (Kookan et al. 2000).

Parameters monitored to evaluate water quality are nutrients and chlorophyll, dissolved oxygen, oil and grease, toxics, and pathogens. Water quality is infrequently monitored in Gloucester Harbor, and long-term data sets do not exist.

Nutrients

Excessive loading of nutrients (primarily nitrogen and phosphorus) in coastal embayments causes eutrophication, resulting in low dissolved oxygen levels, loss of eelgrass beds, increased algal growth, loss of benthic community diversity, and diminished shellfish and finfish productivity (Bricker et al. 1999). The ability of a particular embayment to assimilate nitrogen is a function of tidal flushing, water column mixing characteristics, and land-based nutrient inputs (Bricker et al. 1999). Gloucester was identified as an embayment with high nutrient loading and moderate nitrogen sensitivity (Menzie-Cura 1996).

Chlorophyll a (photosynthetic pigment found in all plants, used as a measure of the biomass of phytoplankton, and used as an indicator of nitrogen pres-

ence) concentrations were reported in the annual monitoring reports for Gloucester Harbor (Michaels 1999; 2000a; 2000b) and 1982 and 1989 state water quality survey reports (DEQE 1982; Duerring 1989). Chlorophyll a was found in higher concentration than would be expected in the open waters of Massachusetts Bay, but levels were not substantially higher (Duerring 1989; Kookan et al. 2000).

Eelgrass is susceptible to high nutrient levels, and eelgrass observed in the outer harbor indicated no unusual growth of epiphytes that would suggest eutrophic conditions (Buchsbaum personal communication). Excessive amounts of macroalgae or drift algae (signal of nutrient problems) were not observed during fish sampling, SCUBA surveys, or a benthic habitat assessment (NAI 1999a; 1999b; Valente et al. 1999). Nutrient inputs may be higher than baseline historic levels, and sources of nutrients entering Gloucester waters exist (e.g., wastewater, septic systems, fish waste, and runoff). Impacts associated with nutrient over-enrichment are not obvious; however, there is no focused monitoring to evaluate nutrient loading or impacts to habitat conditions.

Dissolved Oxygen

Low dissolved oxygen levels in aquatic systems stress marine biota (Diaz and Rosenberg 1995; Diaz and Rosenberg 2001). Several factors contribute to oxygen depletion in harbor waters, including: 1) the introduction of excess organic matter and nutrients (e.g., fertilizers, sewage and fish waste); 2) poor flushing characteristics that limit oxidation through water column mixing; and 3) high salinity and/or temperatures, both of which decrease oxygen solubility (NCSU 2001).

Monitoring in Gloucester Harbor indicated that low dissolved oxygen is not a major problem, although occasional violations of the state standards (i.e., 6.0 mg/l) occurred in the inner harbor (Kookan et al. 2000). Inner harbor experienced low dissolved oxygen episodes, with a range from 0.2 mg/l to 14.1 mg/l (average = 8.6 mg/l) (Rouse 1990). Low dissolved oxygen periods may occur in summer when the water temperature is at a maximum, and water is more likely to be stratified (Rouse 1990). Evidence of depressed oxygen levels, including low seafloor sediment oxidation and colonization of benthos by

opportunistic surface-dwelling fauna, was observed in the inner harbor (Valente et al. 1999). Outer harbor measurements of the water column dissolved oxygen were consistently above 6.0 mg/l (DEQE 1982; Duerring 1989; Rouse 1990; Michaels 1999, 2000a, 2000b), and seafloor conditions improved along a gradient from the inner to outer harbor (Valente et al. 1999; SAIC 2001).

Short-term episodes of depressed dissolved oxygen substantially impact sessile and slow-moving creatures, and localized mortality of benthic macrofauna (e.g., polychaetes, crabs, and lobster) result from hypoxic and anoxic conditions (Diaz and Rosenberg 1995; Diaz and Rosenberg 2001). Indirect impacts to higher trophic levels (i.e., fishes) may also be severe, due to the loss of prey species and alteration of seafloor habitat function. Episodic low dissolved oxygen in the inner harbor stress marine organisms and contribute to degraded benthic conditions. Increased oxygen-depleting pollutants, such as organic matter, and reduced water circulation in the inner harbor exacerbate degraded dissolved oxygen conditions.

Oil, Grease and Toxics

Massachusetts Office of Coastal Zone Management (2001) reviewed ecological effects of various contaminant classes potentially present in Gloucester Harbor. Generalized impacts from a range of pollutants include behavioral (e.g., inhibited spawning), physiological (e.g., reduced respiration rate), cellular (e.g., depressed enzyme function), and life history (e.g., altered growth rates) considerations. Toxic chemicals, including petroleum hydrocarbons, PCBs, pesticides, organic compounds, and heavy metals, enter the marine environment through point discharges and non-point sources.

Oil and grease is a recurring problem for Gloucester Harbor because of fish processing, and WPCF's NPDES permit limits for oil and grease are occasionally exceeded (Kooker et al. 2000). Monitoring associated with the wastewater treatment outfall and CSOs identified copper, nickel, mercury, silver, zinc, and lead in water samples (Metcalf and Eddy 1992; Michaels 2000a; 2000b). Based on water quality criteria (at the wastewater treatment outfall and CSOs), contaminant levels do not indicate acute impacts (Metcalf and Eddy 1992; Michaels 2000a; 2000b).

Contaminant levels in seafloor sediments are influenced by centuries of anthropogenic inputs and existing inputs add to pollutant levels. Seafloor sediments are potentially disturbed by commercial and recreational vessels, and elevated wakes erode and agitate shallow water sediments. The presence of oil, grease, and contaminants in the water column and subsequent accumulation of chemicals in seafloor sediments potentially disrupt environmental resources, such as water quality, and processes (e.g., behavior and growth of organisms) (Wilbur and Pentony 1999).

Pathogens

Diseases affect marine creatures and humans and are an environmental concern for coastal waters throughout Massachusetts. Diseases are caused by viruses, bacteria, fungi, protozoa, and other parasites (marine pathogens are thoroughly reviewed by Sindermann 1996). The prevalence of diseases in coastal waters is often associated with habitat degradation and pollution. Marine organisms, including fish and shellfish, and plants (e.g., eelgrass) are weakened, disabled, or killed by a variety of diseases. Fin erosion, ulceration, decreased pathogen resistance, abnormal development, and depressed metabolism are examples of the consequences of disease to fishes (Sindermann 1996). Shell disease and black gill, for example, affect crustaceans (e.g., American lobster), and reduced growth rates and abnormal shell development are observed in diseased mollusks (e.g., softshell clam and blue mussels). Diseases found in fishes, crabs, and mollusks are not regularly monitored in Massachusetts. Water quality monitoring normally focuses on bacterial contamination (e.g., fecal coliform and *Enterococcus*). These bacteria are used as an indicator of the presence of pathogens for the purposes of shellfish management and bathing beach assessment. Human illness (or death) can occur from consumption of contaminated seafood or direct contact with contaminated water.

Potential sources of pathogen contamination in Gloucester waters include the wastewater outfall, CSOs, failing septic systems, sewage discharge from vessels, stormwater runoff, and marine sediments. Bacterial contamination was a problem throughout the harbor prior to WPCF construction (DEQE 1982). No shellfishing is allowed in Gloucester Harbor, so bacterial sampling is limited to the An-

nisquam River (which is a state-designated conditionally approved shellfish area). High fecal coliform concentrations were found in small streams feeding into Freshwater Cove and Thurston Creek along the Annisquam River (Kookken et al. 2000).

CSO discharges contained levels of fecal coliform and floatables, particularly after precipitation (Metcalf and Eddy 1992). Contamination levels in the inner harbor, which is poorly flushed, often exceed the swimming standard following rain events. The contamination was due to CSOs and stormwater inputs (Duerring 1989). Recent surveys (1995-present) indicate that harbor beaches (i.e., Pavilion, Cressy, Niles, and Half Moon) consistently meet Massachusetts fecal coliform standard (Kookken et al. 2000).

SEDIMENT QUALITY

The chemical and physical properties of seafloor sediments are summarized from existing data sets to describe sediment quality. The investigation of pollution sources and historic sediment data coupled with recent sediment sampling provides a general characterization of sediment quality in the inner harbor and federal channel of Gloucester Harbor and portions of the Annisquam River (Maguire 1997; MCZM 2000). Sediment chemistry and seafloor conditions were examined, as part of the statewide Dredged Material Management Plan (MCZM 2000). Historic sediment samples supplemented the description of sediment chemistry for the Dredged Material Management Plan (Duerring 1989). Sediment cores were collected in the inner harbor and Annisquam River (Figure 2.4).

Identified pollution sources and land-use characteristics of Gloucester contributed levels of contaminants to surficial sediments observed in Gloucester Harbor. To improve previous studies and investigate specific levels of contaminants, 54 cores were collected in the harbor (32 cores) and Annisquam River (22 cores) (Figure 2.4; Maguire 1998). Two samples were analyzed for each core in the North Channel and adjacent to the State Pier to examine chemical characteristics at different sediment layers below the seafloor surface (64 total samples). Samples were analyzed by grain size for chemical composition and

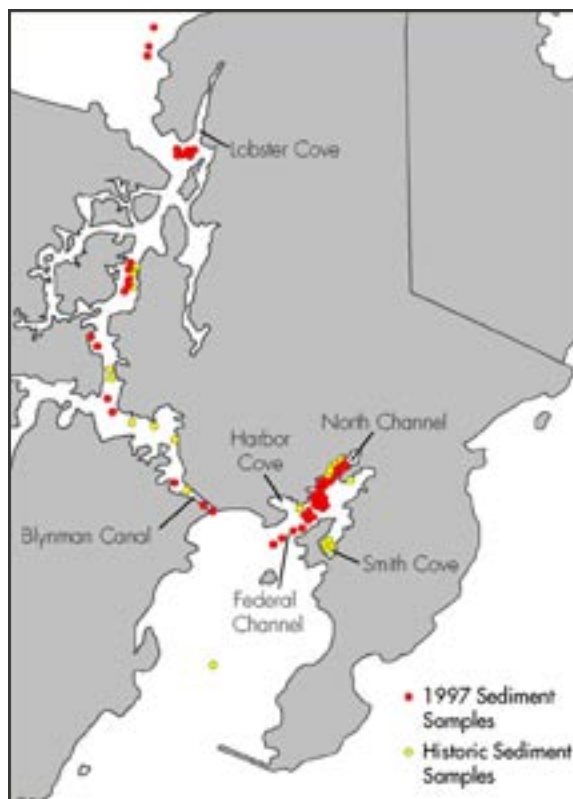


FIGURE 2.4 Sediment sampling locations. 1997 sampling stations (Maguire 1998; MCZM 2000) and 1987-1988 stations (Duerring 1989).

compared to reference samples (i.e., sediment samples from Massachusetts Bay that are considered pristine) (Maguire 1998).

Surficial sediments (top 1 meter) at the entrance of the federal channel heading into the inner harbor and the North Channel were fine-grained, gray to black and anoxic, and high in organic carbon content. Sub-surface sediments (- 2 m to depth) were fine-grained, lean clays, gray, and homogeneous. Thin sand layers were found in subsurface sediments. Outer harbor sediments were predominately very fine sand or silt clay with low organic carbon composition, except areas around the old outfall and inside Dog Bar Breakwater (SAIC 2001). Surficial sediments (top 20 cm) surrounding the old outfall and breakwater were fine-grained with low surficial sediment oxidation, suggesting elevated organic matter and sulfide concentration (SAIC 2001). Annisquam River sediments were composed primarily of sand, but Lobster Cove sediment was characterized by higher fine-grained content.

TABLE 2.1 Summary of sediment chemistry of selected contaminants in Gloucester Harbor – Federal Channel, Annisquam River, and Massachusetts Bay Disposal Site (MBDS) Reference (reproduced from MCZM 2000).

Analytes	Annisquam River		Federal Channel		MBDS Reference
	Mean	Range	Mean	Range	Mean
Arsenic	0.97	0.25 - 3.20	12.00	1.90 - 24.00	28.70
Cadmium	0.17	0.05 - 1.10	0.98	0.15 - 2.40	2.74
Chromium	0.13	4.0 - 70	35.00	11.00 - 41.00	152.00
Copper	9.70	0.50 - 35.0	62.00	10.00 - 140.0	31.70
Mercury	0.05	0.025 - 0.23	0.24	0.025 - 0.43	0.277
Nickel	4.00	1.00 - 10.00	16.70	8.00 - 27.00	40.50
Lead	19.30	1.00 - 71.00	86.00	7.00 - 190.0	66.30
Zinc	55.60	7.0 - 350.0	127.80	48.0 - 310.0	146.00
Total PAH ^a	2670.00	15 - 6803	12372.00	14 - 32670	2996.00
Total PCB ^b	38.00	6.0 - 136.0	113.00	0.0 - 259.0	ng ^c

^aPAH = polycyclic aromatic hydrocarbon

^bPCB = polychlorinated biphenyl

^cng = no guideline.

Chemicals introduced to environment through human activities were found in harbor sediments (Table 2.1). Copper and lead were the most prevalent metals in the federal channel, North Channel, and adjacent to Rocky Neck (MCZM 2000). Zinc, lead, and arsenic were also found during 1987-1988 sampling in the inner harbor (Duerring 1989), and Smith Cove was characterized by elevated concentrations of lead, zinc, copper, and oil and grease (USACE 1990). Total polycyclic aromatic hydrocarbons (PAHs) were substantially higher than reference samples in the North and South Channels (Duerring 1989; MCZM 2000). Pesticides (i.e., dichloro-diphenyl-trichloro-ethane [DDT] and derivatives) and PCBs were found at detectable levels throughout the federal channel (MCZM 2000) and Harbor Cove (Duerring 1989).

PAHs were not detected at uncommon levels in the outer harbor (Duerring 1989). Sediment around the wastewater treatment plant outfall and old outfall location indicate levels of metals at the low end of Massachusetts Bay reference levels (Michaels 2000a; 2000b). Substantial levels of PAHs were found throughout the federal channel (MCZM 2000).

Annisquam River sediments were characterized by low levels of metals, low to moderate PAH concentrations, and notable PCB levels. Lobster Cove generally

presented higher contaminant levels than other areas in the Annisquam. This may be a function of reduced flushing and higher fine-grained sediment composition. Fine-grained sediments tend to accumulate and bind chemicals from the water column.

Highest contaminant levels were generally located in the North Channel, federal channel adjacent to Rocky Neck, and Lobster Cove. Contaminants released into the environment, historic and current, adhere to fine-grained sediments. The presence of copper and lead are common pollutants in nearshore sediments because of upland characteristics, such as the past use of lead in gasoline that enters the marine environment through surface runoff. PAH presence is a result of the incomplete combustion of fuel from power generation, and PAHs are found in runoff, industrial discharge, and atmospheric deposition. Pesticides were widely used to control undesirable organisms and are very stable (i.e., pesticides do not easily decompose), which allows pesticides to persist in the environment. Industrial use of PCBs (e.g., cooling fluids for transformers) may have contributed this pollutant to Gloucester waters, and the PCBs subsequently adhered to seafloor sediments.

The quality of Gloucester's inner harbor seafloor sediments appears fairly typical for an urban waterfront. Nearshore, urbanized coastlines generally

TABLE 2.2 Non-native marine and estuarine species known to inhabit Massachusetts waters (MCZM 2002; Baker personal communication).

Established Species	Threatening Species
European Green Crab	Chinese Mitten Crab
Japanese or Asian Shore Crab	Veined Rapa Whelk
Lace Bryozoan	Pacific Oyster
Periwinkle Snail	European mussel
Ascidians (tunicates and sea squirts)	Shipworm (<i>Toredo</i> spp.)
Colonial Hydroid	<i>Caulerpa</i> (aquatic plant)
Sea slug	<i>Nori</i> (red algae)
Shellfish Pathogens: MSX, Sea Side Organism (SSO), Dermo, Quahog Parasite Unknown, (QPX)	
Dead Man's Fingers (<i>Codium fragile</i>)	
Common Reed (<i>Phragmites</i> spp.)	
Purple Loosestrife	

present higher concentration of contaminants than reference areas that are not heavily influenced by anthropogenic sources (Gould et al. 1994). Elevated levels of contaminants were also found in seafloor sediments of the nearby urban waterways of Salem Harbor (Wilbur and Babb-Brott 2000). Toxics, at particular concentrations in seafloor sediments or suspended in the water column, pose several potential risks to ecological integrity and human health, including: 1) acute and chronic toxicity to marine life; 2) bioaccumulation, causing a public health risk; and 3) long-term contaminant source. Long-term exposure to contaminants found in seafloor sediment present a range of reproductive, behavior, physiological, cellular, and survivorship effects to marine creatures (MCZM 2001).

INVASIVE SPECIES

Gloucester Harbor contains possible transport mechanisms that intentionally or unintentionally introduce nonindigenous (or invasive) creatures. Vectors include the seafood industry, commercial fisheries, industrial shipping, and recreational boating. The introduction of nonindigenous species is associated with human activities and may congregate in areas of active port operations. The release of nonindigenous species into Massachusetts waters started during early colonization and continues (and is possibly

expanding) with globalization and rapid movement of people and goods (MCZM 2002). Established and threatening species are found throughout Massachusetts waters (Table 2.2; MCZM 2002).

Gloucester Harbor was assessed to determine the presence of macroinvertebrate and algal invasive species at the State Pier and Cape Ann Marina. Twelve and nine invasive species were found at the State Pier and Cape Ann Marina, respectively (Pederson personal communication). Nonindigenous creatures can change natural community structure and dynamics by competing with native species, degrading existing conditions, and transmitting or introducing disease (Wilbur and Pentony 1999). Invasive species present serious economic implications, including the displacement of fishery and forage species and destruction of coastal infrastructure by fouling organisms, and ecological consequences (e.g., decline in biological diversity and alteration of community structure).

CUMULATIVE IMPACTS

Environmental quality is not exclusively influenced by individual threats. Pollutants, physical alteration, and introduced threats can individually or simultaneously alter and degrade environmental conditions. Cumulative impacts are the combined

outcome of numerous actions and stresses that alone may present limited implications but combine to substantially impact environmental resources (Vestal et al. 1995). The urban nature of Gloucester Harbor presents many human-induced threats and pollutants. Traditional harbor development, exploitation of resources, and current pollutant sources dictate environmental quality. Dock and pier construction, wetland filling, channel dredging, and coastal development each impacted Gloucester resources. Runoff, CSO and stormwater discharges, and contaminated sediments—for example—continue to influence harbor conditions. Efforts to understand individual impacts associated with one pollutant improve resource management decisions to limit or eliminate a particular threat. However, there are many threats, and each warrants attention and consideration in the discussion of Gloucester Harbor's environmental integrity.

SUMMARY

The environmental quality and integrity of Gloucester Harbor is typical for an urban port, characterized by areas of degradation and areas of limited human perturbation. The inner harbor, including Harbor Cove and Smith Cove, reflects a higher degree of human impacts than the outer harbor, as indicated by prevalent sediment contamination and episodic low dissolved oxygen levels. The physical characteristics (i.e., restricted coves with poor flushing) and the intensity of development influence the environmental conditions of the inner harbor. Lobster Cove accumulated contaminants due to reduced tidal action and pollutant input. The outer harbor exhibits human influences, but to a lesser degree than the inner harbor. Systematic, long-term monitoring of water quality, sediment quality, or habitat function does not exist for Gloucester waters. Trends of the environmental integrity and quality of Gloucester Harbor are difficult to ascertain or describe with the lack of monitoring and targeted research.

ACKNOWLEDGMENTS

This study was funded by the Massachusetts Office of Coastal Zone Management Grant. Fara Courtney (Good Harbor Consulting) spent hours with Gloucester officials and staff searching for historic records. CZM staff (Anne Donovan) reviewed earlier versions of the report.

LITERATURE CITED

- Barr, B.W. 1987. Dredging handbook: A primer for dredging in the coastal zone of Massachusetts. Massachusetts Coastal Zone Management, Boston.
- Bricker, S.B., C.G. Clement, D.E. Pirhalla, S.P. Orlando, and D.R.G. Farrow. 1999. National Estuarine Eutrophication Assessment: Effects of nutrient enrichment in the nation's estuaries. NOAA, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science. Silver Spring, MD. 71pp.
- DeCasare, G. J., L. E. Kennedy and M. J. Weinstein. 2000. North Coastal Watershed 1997/1998 Water Quality Assessment Report. Massachusetts Department of Environmental Protection, Division of Watershed Management.
- Department of Environmental Water Quality Engineering (DEQE). 1982. Gloucester Harbor Water Quality Data 1980 & 1982. Massachusetts Division of Water Pollution Control, Westborough, MA.
- Diaz, R.J. and R. Rosenberg. 1995. Marine Benthic Hypoxia: A review of its ecological effects and the behavioral responses of benthic macrofauna. *Oceanography and Marine Biology* 33:245-303.
- Diaz, R.J. and R. Rosenberg. 2001. Overview of Anthropogenically-Induced Hypoxic Effects on Marine Benthic Fauna. In *Coastal Hypoxia: Consequences for Living Resources and Ecosystems*. Coastal and Estuarine Studies. 129-146.
- Duerring, C. L. 1989. North Coastal Water Quality Surveys 1987 and 1988. Massachusetts Department of Environmental Quality Engineering, Westborough, MA.
- Flemming, G. 1982. Join Harbor Swim: Make a Point and Then.... Gloucester Daily Times, August 13, 1982.
- Gould, E., P.E. Clark, and F.P. Thurberg. 1994.

- Pollutant effects on demersal fishes. In, R.W. Langton, J.B. Pearce, and J.A. Gibson, editors. Selected living resources, habitat conditions, and human perturbations of the Gulf of Maine. NOAA Technical Memorandum NMFS-NE-106, Woods Hole, MA.
- ICON Architecture, Incorporated (ICON). 1999. Gloucester Harbor Plan. Prepared for the Gloucester Harbor Plan Committee, Gloucester, MA.
- Kooken, V., C. Dunn, C. DelPapa, and R. Buchsbaum. 2000. Water Quality Assessment: Gloucester Harbor, North River, Salem/Peabody, Saugus River, Smallpox Brook, Salisbury. Prepared for: The Massachusetts Executive Office of Environmental Affairs. 55pp.
- Maguire Group Inc. (Maguire). 1997. Dredged Material Management Plan Phase 1, Volume I, Gloucester, Salem, New Bedford and Fall River. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA.
- Maguire Group Inc. (Maguire). 1998. Massachusetts Dredged Material Management Plan – Sediment Chemistry Results: Fall River, Gloucester, New Bedford-Fairhaven and Salem. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA.
- Massachusetts Office of Coastal Zone Management (MCZM). 2000. Dredged Material Management Plan (DMMP) EOE No. 11534. Draft Environmental Impact Report (DEIR) for Gloucester, Massachusetts. Prepared by: Maguire Group Inc., Foxborough, MA.
- Massachusetts Office of Coastal Zone Management (MCZM). 2001. Essential Fish Habitat (EFH) Assessment: Gloucester Harbor, Massachusetts. Prepared by: Maguire Group, Foxborough, MA. Prepared for: Massachusetts Office of Coastal Zone Management, Boston, MA.
- Massachusetts Office of Coastal Zone Management (MCZM). 2002. Draft – Massachusetts Aquatic Invasive Species Management Plan. Prepared by Massachusetts Office of Coastal Zone Management. Boston, MA.
- Menzie-Cura & Associates, Inc. 1996. Identification of Massachusetts Bays Embayments at Risk of Eutrophication. Prepared for the Massachusetts Bays Program. Boston, MA.
- Messieh, S.N., T.W. Rowell, D.L. Peer, and P.J. Cranford. 1991. The effects of trawling, dredging and ocean dumping on the eastern Canadian continental shelf seabed. *Continental Shelf Research* 11:1237-1263.
- Metcalf & Eddy Incorporated. 1992. Final Report to the City of Gloucester: Combined Sewer Overflow Facilities Plan. Vols. I, II, III. Gloucester, MA.
- Michaels, A.D. 1999. Gloucester 301(h) Monitoring Program 1996 Annual Report. Magnolia, MA.
- Michaels, A.D. 2000a. Gloucester 301(h) Monitoring Program 1998 Annual Report. Magnolia, MA.
- Michaels, A.D. 2000b. Gloucester 301(h) Monitoring Program 1997 Annual Report. Magnolia, MA.
- Normandeau Associates Incorporated (NAI). 1999a. Dredged Material Management Plan – Fisheries resources survey for New Bedford. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA. 28pp. + append.
- Normandeau Associates Incorporated (NAI). 1999b. Dredged Material Management Plan – Fisheries resources survey for Gloucester. Prepared for Massachusetts Office of Coastal Zone Management, Boston, MA. 28pp. + append.
- North Carolina State University Water Quality Group (NCSU). 2001. Internet site: <http://h2osparc.wq.ncsu.edu>. February 2001.
- Rouse, L. A.. 1990. Gloucester Harbor Monitoring Report 1982-1989. Massachusetts Audubon Society: North Shore. Wenham, MA.
- Science Applications International Corporation (SAIC). 2001. Results of the March 2001 sub-bottom profiling and sediment profile imaging survey of the outer Gloucester Harbor. Prepared for: Massachusetts Office of Coastal Zone Management, Boston, MA.
- Sindermann, C.J. 1996. Ocean Pollution: Effects on Living Resources and Humans. The CRC Marine Science Series. CRC Press, Boca Raton, FL.
- Valente, R.M., M.C. Swanson, and C.L. Seidel. 1999. Dredged Material Management Plan: Habitat characterization of the DMMP potential aquatic disposal sites. Science Applications International Corporation Report No. 463. Prepared for Massachusetts Office of Coastal Zone Management.
- Vestal, B.A. Rieser, M. Ludwig, J. Kurland, C. Collins, and J. Ortiz. 1995. Methodologies and mechanisms for management of cumulative coastal environmental impacts. Part I – synthesis, with annotated bibliography; Part II – development and

- application of cumulative impacts assessment protocol. NOAA Coastal Ocean Program Decision Analysis Series No. 6. NOAA Coastal Ocean Office, Silver Spring, MD.
- Whitman & Howard. 1958. Report on the Existing Sewerage System and Improvements Thereto: City of Gloucester, MA.
- U.S. Army Corps of Engineers (USACE). 1990. Small Navigation Project Detailed Project Report: Smith Cove. Department of the Army Corps of Engineers, New England Division. Concord, MA.
- U.S. Army Corps of Engineers (USACE). 1996. Inventory of dredging needs in the Designated Port Areas of Massachusetts: 1996-2016. Conducted by the USACE, New England Division for Massachusetts Office of Coastal Zone Management.
- Wilbur, A.R. and D. Babb-Brott. 2000. Sediment quality and seafloor features. Presentation at State of the Sound: Current Knowledge and Future Directions. A symposium on the health of the Salem Sound Ecosystem. 25 May 2000, Salem State College, Salem, MA.
- Wilbur, A.R. and M.W. Pentony. 1999. Human-induced nonfishing threats to Essential Fish Habitat in the New England region. In, L. Benaka, editor. Fish Habitat: Essential Fish Habitat and Rehabilitation. American Fisheries Society Symposium Proceedings 22:299-321.

Personal Communication

- Baker, Jason.** Massachusetts Office of Coastal Zone Management. Boston, MA.
- Buchsbaum, Robert.** Personal Communication. North Shore – Massachusetts Audubon Society. Wenham, MA.
- Pederson, Judith.** Massachusetts Institute of Technology Sea Grant College Program. Cambridge, MA.